APPENDIX H

TECHNICAL MEMORANDUM:
Use Life-Cycle Stage Approach

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1. INTRODUCTION

1.1 Background

As part of the Environmental Protection Agency's Design for the Environment Program (DfE) Computer Display Project (CDP), the University of Tennessee Center for Clean Products and Clean Technologies is conducting an environmental life-cycle assessment (LCA) of 17" cathode ray tube (CRT) and 15" active matrix liquid crystal display (LCD) computer monitors. Chapter 1 of this report provides further details about the scope and boundaries of this project. As typically defined in LCA, the five main life-cycle stages of any product are as follows:

- Materials Extraction;
- Materials Processing;
- Product Manufacture;
- Product Use, Maintenance and Repair; and
- End-of-Life.

This technical memorandum (TM) presents the CDP's approach to developing the inventory that will be used to assess the environmental and health impacts from the use life-cycle stage of computer monitors. Maintenance and repair are not included within the boundaries of this analysis because they are expected to be minor contributors to environmental impacts compared to use and other life-cycle stages.

The purpose of this TM is to present the approach for developing the inventory of inputs and outputs associated with the actual use of the monitors. The final use-stage inventory will consist of electricity consumption from use as well as the indirect inputs and outputs from the generation of that electricity. The focus of this TM is on identifying the amount of electricity consumed during use. The inventory from electricity generation is presented in Appendix E. The final use-stage inventory combines these two sets of data and will be presented as part of the final LCI in Section 2.7 and Appendix J of this report.

In addition to energy consumption, other environmental or health issues have been associated with the use of computer monitors, including eye strain, ergonomics, and exposure to electric and magnetic fields. However, quantitative methods for assessing these impacts within the project LCA framework are not available. Thus, these impacts will be addressed qualitatively in the final LCA report for the project.

1.2 Calculating Energy Consumption During the Use Stage

CRTs and LCDs use different mechanisms to produce images on screen, which result in different energy use rates. These energy use rates can be combined with the number of hours a desktop monitor is on during its lifespan to calculate the total quantity of electrical energy consumed during the use life-cycle stage. In this project, two lifespan scenarios are considered:

- Manufactured life - the amount of time either an entire monitor or a single component will last before reaching a point where the equipment no longer functions, independent of user choices.
- Effective life - the actual amount of time a monitor is used, by one or multiple users, before it is disposed of, recycled, or re-manufactured. Reuse of a monitor by a subsequent user is considered part of its effective life. Recycling, on the other hand, is the reuse of parts or materials that require additional processing after disassembly and it is not considered part of the use stage.

These two scenarios are considered in this project in order to account for potential differences between how consumers *currently* use the equipment and how consumers could use the equipment. Currently, consumers often replace monitors before they physically break down. This behavior results in a lifespan that is not dependent on the monitor technology itself. The manufactured life, on the other hand, is based on the technology and represents how consumers could potentially use the equipment. If the lifespans are significantly different, the difference could have a large impact on how the use stage compares to the other life-cycle stages in this study. The remainder of this TM is broken down into the following sections: Methodology, Preliminary Results, Data Sources and Quality, Limitations and Uncertainties, and Discussion and Conclusions.

2. METHODOLOGY

As discussed in the previous section, calculating electrical energy consumption during the life of an electrical component requires two main pieces of information: the component's energy use rate (typically in watts or kilowatts) and the amount of time the component can or does spend in use (in hours per life).

Once energy use rates and hours per life in each mode are known, they can be multiplied to derive the total number of kilowatthours (kWh) consumed during the lifetime of a monitor according to the following general equation where " mode *I*" indicates the power consumption mode of a monitor (i.e., full-on or low, discussed further in Sect. 2.1). This basic equation will be used to calculate the total kWhs consumed over the manufactured and effective lives for LCDs and CRTs.

$$\sum_{i=1}^{2} \left[(kW \text{ consumed in mode } i) \times \left(\frac{hours}{life} \text{ spent in mode } i \right) \right] = \frac{kWh}{life}$$

Section 2.1 presents information on the various energy use rates that exist for the project functional units in different power modes. Section 2.2 presents the methodology for calculating hours per life under the manufactured and effective life scenarios.

2.1 Energy Use Rate

Most desktop monitors manufactured today are built to use several different power consumption modes during normal operation. There are often up to four different power consumption modes that can be used by a monitor in going from a state of active use to a state of almost complete shut-down. These four modes, from greatest power consumption to least, are typically entitled 'full-on' or active use, 'standby,' 'suspend' and 'active-off.' For this TM, manufacturers' data on these power modes were collected from company contacts and Internet sites for 35 different 17" CRT monitors and 12 different 15" LCD monitors. The complete list of these data is presented in Attachment A, Table A1.

For the purposes of this TM, the power consumption modes have been categorized into two modes: 'full-on' and 'low.' The 'low' power mode is an average of the three low power modes typically provided by the manufacturers (i.e., standby, suspend, and active-off). These three categories were averaged to create one 'low' power consumption mode because hours per use data (needed for calculations in this TM) are only available for a 'full-on' and a reduced power mode. The low mode value for the CRT is the average of the three modal averages of standby, suspend and active-off. For the LCD, data on only two low-power modes (standby and active-off) were provided by manufacturers (see Attachment A, Table A2), and therefore, the low mode value is an average of those two modal averages. Table 1 presents the average values for full-on and low power modes that were used for subsequent calculations in this TM.

Table 1. Average Energy Use Rates [a]

Monitor Type	Full-on Power Mode		Low Power Mode [b]	
	(W)	(kW)	(W)	(kW)
17" CRT	112	0.113	13.1	0.013
15" LCD	39.7	0.040	6.44	0.006

[a] See Attachment A, Table A1 for source data.
[b] An average of company-reported values for standby, suspend and active-off (see Attachment A, Table A1).

2.2 Calculating Lifespan

As stated previously, lifespan calculations in this TM are based on two different scenarios: manufactured life and effective life. Sects. 2.2.1 and 2.2.2 present the methodology and data needed to calculate energy use under each of these two scenarios, respectively. Sect. 2.2.2 is further divided into discussions of office versus home use patterns, the amount of time a monitor is operating in each power mode, and the number of years the monitor is operating in its lifetime. These results will be combined with data from the energy use rate calculations in Sect. 2.1 to obtain the energy consumption per life for each scenario and for each monitor.

2.2.1 Scenario #1: Manufactured Life

The manufactured life is defined here as the length of time a monitor is designed to operate effectively for the user. It is the number of hours a monitor would function as manufactured, and is independent of user choices or actions. One way to estimate this manufactured life is to use the mean-time-before-failure (MTBF) specification of a monitor or its components. The CRT MTBF specification dictates the amount of time the display must operate before it reaches its brightness 'half-life,' or the ability to produce 50% of its initial, maximum brightness. The MTBF value, generally provided in total hours per life of a monitor, is what most final manufacturers or assemblers of personal computer (PC) equipment, including monitor assemblers, typically specify for a component. To meet the specification, suppliers typically calculate the MTBF (a military-based specification) based on component data. Suppliers' test results are usually called the 'calculated' MTBF. The MTBF value also depends on which combination of power modes are used during testing, which is referred to as the 'duty cycle' and each supplier may use a different duty cycle to test their component.

Additionally, monitor assemblers will often perform their own testing, typically entitled 'demonstrated' MTBF. The testing includes sequences where the monitor is 'stressed' by quickly switching back and forth from an all black picture to an all white one, or quickly switching individual pixels either on and off or through multiple colors or black and white. Manufacturers typically find that their demonstrated MTBF is on the order of twice as long as the calculated MTBF (McConnaughey 1999, Douglas 1999). However, it should be noted that the demonstrated MTBF is not a real-time testing method, as the testing data is used in a complex equation to calculate that 'demonstrated' value.

From review of the information obtained on CRT-based monitors (see Attachment A, Table A2), it appears that the CRT itself is the limiting component, or the component that 99% of the time determines whether the entire monitor has reached its end-of-life. Thus, from the limited information that was obtained on CRTs, and the limited confidence that can be instilled in that data, an average of the two ranges obtained on the estimated lifetime of CRTs (10,000 - 15,000 hours) was used as the CRT manufactured lifetime (12,500 hours) (Goldwassar 1999, Douglas 1999).

For active matrix LCDs, the components that have the greatest potential to fail first are the display panel itself (including the liquid crystals and thin-film transistors), backlights, driver integrated circuit (IC) tabs, and other smaller components. The backlights and driver IC tabs can be field-replaced, thus their failure does not necessarily represent the end of the monitor's life. However, failure of the liquid crystals or transistors, which would require replacement of the display panel itself, would most likely mean that the monitor cannot be cost-effectively repaired. The MTBFs of all these components appear to have a broad range. For example, different backlight manufacturers reported from as few as 15,000 hours to as many as 50,000 hours (Douglas 1999, Tsuda 1999, VP150 1999). However, it appears that those components that are not field-replaceable (e.g., the LCD panel) have MTBFs in the range of 40,000 - 50,000 hours (Tsuda 1999, Young 1999). Thus in this TM, the amount of time an LCD monitor would operate during its manufactured life is assumed to be the average of the two non field-replaceable values, or 45,000 hours. In order for a monitor to operate for 45,000 hours, any major field-replaceable parts that have MTBFs less than 45,000 hours will need to accounted for in this LCA project. For example, assuming the backlights last on average 32,500 hours (the average of the values obtained for backlights), two would be needed for every panel during its lifetime. Therefore, in the final CDP LCA, the manufacturing of these type of components would need to be included in the inventory.

Little information is available on the duty cycles that component manufacturers use to test components. Thus, it is assumed that the average duty cycle utilized in testing components is 50% of the time tested in full-on mode and 50% in a lower power mode. Table 2 shows the values that are used in this TM for the hours per manufactured life for the CRT and LCD. The LCD manufactured life (45,000 hours) is 3.6 times greater than the CRT manufactured life (12,500 hours). Therefore, based on equivalent use periods, 3.6 CRTs would need to be manufactured for every single LCD.

Table 2. Manufactured Life Values

Monitor Type	Total Hours (hours/life)	Mode	Duty Cycle (% time spent in each mode during testing)	Hours per Mode (hours/life)
17" CRT	12,500	Full-on	50%	6,250
		Low	50%	6,250
15" LCD	45,000	Full-on	50%	22,500
		Low	50%	22,500

2.2.2 Scenario #2: Effective Life

The effective life scenario attempts to model the actual quantity of hours that an average monitor spends in each of the two primary power consumption modes (full-on and a lower power state) during its lifetime. The effective life of an average monitor is based on the following information:

- The proportion of computers that are used in an office environment versus a home environment, to account for different use rates in these two basic user environments;
- The amount of time in a year a typical monitor spends in full-on power mode and in a lower power-consuming mode for both office and home environments; and
- The number of years a typical monitor is used during its lifespan for both office and home environments, not including years in storage before a monitor is replaced or discarded (as it is not consuming power during storage).

Under this lifespan scenario, we assume there is no difference in the amount of time a CRT or LCD monitor is operating. That is, the hours per life for the effective life calculation is not technology-dependent. Therefore, the same set of hours-per-life values are used to calculate the kWhs used per effective lifetime for a CRT and an LCD. The remainder of this section discusses the data and methods used to calculate the final hours-per-life values used in the effective life scenario. In order to obtain these final values, we need to determine the percentage of office versus home environment users, the annual use operating patterns in the office and home environments (hours/year) within each power mode, and the number of years a monitor is in operation during life. The following three subsections address these data needs.

2.2.2.1 Percentages of Office- and Home-Environment Users

Home and office users of computer equipment do not follow the same use patterns. Thus, data are needed on the percent of users in each environment to determine the use pattern of an "average" computer monitor. The most recent data available for both home and office users are for 1997. The Computer Industry Almanac for 1997 reports an estimated 117 million total computers were in use in the United States in 1997 (CIA 1997). In addition, the 1997 Residential Energy Consumption Survey (RECS) reports that 43 million PCS were used in homes in 1997 (EIA 1999). Therefore, assuming the remaining non-household computer monitors are all in office environments, there would be approximately 74 million computers being used in office environments.

Note that an 'office' environment may be a school, hospital, or other commercial environment, and the computers they use may follow widely varying degrees of use. For example, computers (and thus monitors) in a school may only be used a few hours in a day, while hospitals might operate theirs nearly constantly. For this TM, it is assumed that on average, typical office use patterns (to be presented in Sect. 2.2.2.2) are representative of all non-home environment users.

The 1997 RECS also reported that 6% of the 43 million household computers were used to telecommute (EIA 1999), which equals approximately 2.6 million computers. The use pattern of a telecommuter is assumed to resemble more closely an office environment than a home environment; therefore, the number of office environment monitors is assumed to total 76.6 million. Therefore, for purposes of calculations in this TM, the percentage breakdown of office and home environment monitors in the United States is as follows:

- Office: (74 million + 2.6 million) / 117 million = 65%
- Home: (43 million - 2.6 million) / 117 million = 35%.

2.2.2.2 Operating Pattern (Average Hours in Use Per Year)

In order to determine the amount of electricity consumed during a monitor's effective life, we need to know the use operating patterns for both the office and home environments. The 'operating pattern' is defined here as the number of hours per year spent in each power mode. The average number of hours per mode per year will be the weighted average of the two user environments (i.e., 65% office, 35% home).

A literature search for computer monitor operating patterns was conducted for both office and home environments and a summary of literature reviewed is presented in Attachment A, Table A3. For data on office environment operating patterns, the most relevant and complete information found was from work performed by Lawrence Berkeley National Laboratory (LBNL) presented in a report entitled "Measured Energy Savings and Performance of Power-Managed Personal Computers and Monitors" (Nordman et al. 1996). Their definition of the standard operating pattern was based on earlier work performed by LBNL that studied electricity use by office equipment in commercial buildings, and referenced multiple studies on the use of office equipment, some having sample sizes as large as several hundred systems. Table 3 presents the standard office operating pattern for three different types of days (workday, weekend day and absence day), based on Nordman et al. (1996). Note that Nordman et al. "...first distinguish between weekdays and weekend days, with the latter including only Saturdays and Sundays. Then, any weekday which has less than half an hour of on-time (full-on or low power) is considered an absence day; the rest of the weekdays are workdays." Therefore, absence days may include some hours in operation. Also, some individuals may leave their computers on while out of the office, also resulting in hours in operation while the user is out of the office.

Table 3. Standard Office Operating Pattern[a]

Type of Day	Standard Office Operating Pattern			
	On			Off
	Full-on	Low	Total	
Workday (hr/day)	4.1	8.4	12.5	11.5
Weekend Day (hr/day)	0.0	4.8	4.8	19.2
Absence Day (hr/day)	0.0	4.8	4.8	19.2
Average Day[b] (hr/day)	2.3	6.9	9.2	14.8

Source: Adapted from Nordman et al. 1996, based on percentage of time in each mode.
[a] Based on the assumption that all monitors take advantage of low power modes.
[b] To calculate the average day, an average week is assumed to consist of 4 workdays, 2 weekend days, and 1 absence day per week. Average monitor usage per day weighs each average day by the number of each day type in a week.

Using the hours per day for the three basic day types, we created an average annual day for the purposes of eventually obtaining an annual average. To calculate the average day, we assumed that a typical week of computer use in the year contains 4 workdays, 2 weekend days, and 1 absence day. By including 1 absence day in the typical week, the calculation results in 52 days annually that are days of no active computer system use, and are intended to include the following: holidays, sick days, vacations, work travel and days when computers are not needed for work or are not in use in the office.

LBNL's operating patterns do not appear to take into account whether or not a monitor is actually taking advantage of the various power savings modes. In their 1996 study, Nordman et al. found that only one-third of the monitors were set up to recognize time-based indicators that power down a part of the monitor or part of the PC that sends information to the monitor. More recently, a representative of the EPA Energy Star Program estimated that approximately 90 - 95% of those monitors manufactured and sold in tandem with a PC in 1998 were pre-set up to take advantage of the multiple power consumption modes of the monitor, without any setup by the user (Fanara 1999). However, monitors are also sold individually, and no statistics were found on how many are sold that way and what percent of those are able to work with a PC's energy savings systems without assistance from the user. For the purposes of this TM, we assume that 90% of the monitors manufactured in 1998 and in use today are set up to recognize the power management signaling either from the monitor itself or from the PC to which they are connected. The lower end of the 90 - 95% range was chosen to recognize that monitors sold separately were not accounted for, and also, from an environmental impact perspective, it is conservative to assume a lower percent, which means less use of power saving features and greater energy consumption.

It should also be noted that this 90/10 split takes several assumptions into account, including but not limited to the percentage of users who alter or change their PC's and/or monitor's energy-saving settings, the percentage of users who know how to alter or change their PC's and/or monitor's energy-savings settings and the number of small-sized companies that build PC systems and whether or not they configure their systems to be able to take advantage of energy-savings settings 'out-of-the-box.' Because our confidence in this percentage split is not high, we will perform a sensitivity analysis of different percentage breakdowns of using low power modes versus not using them (50/50, 75/25, and 100/0; presented in Sect. 3.3).

This 90/10 split of using versus not using the power saving modes is implemented in the calculations by adjusting the average amount of hours per day a monitor spends in each mode for the effective life calculations (see Table 3). Thus, 10% of the value of each number in the 'Low' column of Table 3 was removed and added to the 'Full-on' value in that same row, to account for those that cannot go into a lower power-saving mode. Table 4 presents the adjusted figures for hours per day and presents the annual average values by multiplying the average day values by 365 days. The average day is calculated in Table 4 the same way it was calculated in Table 3.

Table 4. Adjusted Office Operating Pattern[a]

Type of Day	Adjusted Office Operating Pattern			
	On			Off
	Full-on	Low	Total	
Workday (hr/day)	4.9	7.6	12.5	11.5
Weekend Day (hr/day)	0.48	4.3	4.8	19.2
Absence Day (hr/day)	0.48	4.3	4.8	19.2
Average Day[b] (hr/day)	3.0	6.2	9.2	14.8
Annual Average (hr/yr)	**1,095**	**2,263**	**3,358**	**5,402**
Percent on time spent in each mode	33%	67%	100%	-----

[a] Values in Table 3 have been adjusted based on the assumption that 90% of monitors can take advantage of low power modes. Therefore, 10% of the hours in low mode in Table 4 were added to the full-on column and subtracted from the low column in this table.
[b] To calculate the average day, an average week is assumed to consist of 4 workdays, 2 weekend days, and 1 absence day per week. Average monitor usage per day weighs each average day by the number of each day type in a week.

For the home environment operating patterns, the most relevant and complete information was found in the RECS report (EIA 1999). The survey contained data on the use of computers in the home and how many hours per week the users have their computer on, without distinguishing power mode. Table 5 reveals the information obtained from the RECS report and breaks that data down to calculate a daily average and then an annual average operating pattern (i.e., the total number of hours of on time in one year).

Table 5. RECS Home Operating Pattern Breakdown

Use Frequency Category	U.S. Households with Computers (EIA 1999)		Average Hours in Use for Each Category	Average Household Use[a]
	(millions of households)	(% of households)	(hours/week)	(hours/week)
Less than 2 hours per week	8.2	23.0%	1	0.2
2 to 15 hours per week	17.4	48.9%	8.5	4.2
16 to 40 hours per week	6.7	18.8%	28	5.3
On all the time	3.3	9.3%	168	15.6
Totals	35.6	100.0%	-----	25.2
Daily Average (hours per day)				3.6
Annual Average (hours per year)				**1,315**

Note: Totals may not be additive due to independent rounding.
[a] These values are the product of the fraction of households in each category and the average hours per week in each category.

Data on the amount of time a home-environment monitor is in full-on versus a lower power mode was not provided in the RECS, nor was such data found elsewhere. Thus, lacking any other information, we have chosen to use the percentage breakdown found in the office-environment data for the home-environment data in this TM (see the bottom row of Table 4). These percentages are applied to the total 1,315 hours/year for home-environment use to estimate the amount of time in each mode. In addition, the 90/10 split of equipment that can/cannot go into lower power saving modes was applied to these values to determine the actual expected number of hours per year per mode for the home environment. In Table 6, the hours per year values for each power mode are shown. In order to determine these hours spent in each mode, the total number of hours spent on annually (1,315 hours/year) was first split by the 90/10 factor into equipment that can and cannot save energy categories. Then, the resulting 1,183 hours/year was split by the office-environment data on the percent of time spent in each mode, resulting in 390 hours annually in full-on mode and 793 hours annually in a lower power mode. The remaining 132 hours/year that cannot go into an energy saving mode, was included in the 'Full-on' row. The two values for each row are then added to obtain the total hours annually in a home environment that a monitor would spend in each power mode.

Lastly, Table 7 shows the final values obtained for the effective life calculations, as presented in this section, for hours per year per mode for office- and home-environment users.

Table 6. Splitting the Home Operating Pattern Data into the Two Power Modes

Power Mode	Percent of Time in Each Mode (from office- environment data)	Time Operating in Each Mode (hours/year)		
		90% That Can Save Energy	10% That Cannot Save Energy	Total
Full-on	33%	390	132	**522**
Low	67%	793	0	**793**
Total	100%	1,183	132	1,315

Table 7. Summary of Operating Patterns for Effective Life Calculations

User Environment	Time Operating in Each Environment (hours/year)		
	Full-On Power Mode	Low Power Mode	Total
Office	1,095	2,263	3,358
Home	522	793	1,315

2.2.2.3 Average Years Per Life

The third set of values required for the calculation of hours per effective life is the number of years of use in the life of a monitor. The number of years per effective life, multiplied by the operating patterns in hours per year (presented in Table 7), will result in the hours per effective life.

A monitor may be reused in multiple 'lives' before reaching its end-of-life. The end-of-life is defined as the point at which the monitor is no longer used for its intended purpose in the physical form in which it was originally manufactured. End-of-life options include indefinite storage (in which case it is not reused after storage), de-manufacturing, recycling, or disposal. A monitor may be stored before being reused; however, this storage time will not affect our use calculations since no electricity is required to operate the monitor during this storage. After its first life as used by the original owner, a monitor might be used by different people and with different PC systems in subsequent lives.

For data on the number of years of use that are in a monitor's lifetime, several sources of information were reviewed. Two particular studies provided relevant data on the number of years per life (Matthews et al. 1997, NSC 1999). A study by Matthews et al. (1997), which was an update to a study originally performed in 1991, concluded that after a first life of 5 years, approximately 45% of all PC systems are reused, while the remaining 55% either go directly to recycling or landfilling (10%) or are stored and then recycled or landfilled (45%). Their study only addressed PC systems as a whole and did not break down the lifetimes of individual components. Additionally, they concluded that the period over which the systems are reused is 3 years.

In a recently completed study for the National Safety Council (NSC 1999), researchers interviewed more than 30 major manufacturers and resellers of CRT computer monitors and other computer components. NSC found that a CRT monitor's first life lasts approximately 4 years, while the total lifespan is on the order of 6 - 7 years. Since the NSC study contains results that pertain specifically to monitors, and provides the most recent data, its results are used in this TM. The values that are used for calculations in this section are 4 years for the first life of use, and 2.5 years for the second and subsequent lives of use. The operating pattern for monitors in all the years over its effective life (6.5 years) are assumed to be the same as presented in Sect. 2.2.2.2 (Table 7). However, in the lives subsequent to the first life, the hours per year values are reduced by the fraction of monitors assumed to be reused. Matthews et al. (1997) estimated that 45% of PCS are reused after a first life; thus, the effective life operating pattern values in years of life after the first life are 45% of the values in the first life (which were presented in Table 7).

While the NSC data singled out CRT monitors in their lifespan estimates, they did not single out desktop LCD monitors. Their data did contain estimates of a 'Notebook PC,' which were 2 - 3 years for the first life and 1 - 2 years for the remaining lives, however, we expect that desktop LCD monitors will more closely mirror the lifetime estimates of a desktop CRT monitor than that of a notebook PC. Consequently, it was assumed that LCD desktop monitors also spend 4 years in their first life and 2.5 years in their subsequent lives. Additionally, the NSC document did not attempt to separate those computer systems or monitors that are used in an office versus a home environment. Thus, it was assumed that the same years per life are realized for office and home environments.

2.2.2.4 Summary of Effective Life Values (Hours per Life)

Data presented throughout Sect. 2.2.2 that are needed to estimate the hours per effective life, are shown in Table 8. The values for hours per year per power mode, calculated in Sect. 2.2.2.2 and presented in Table 7 are assumed to be the operating pattern throughout the first life (first four years). In the remaining lives, the annual operating hours decreases to 45% of the hours in operation during each year in the first life, with the remaining lives lasting a total of 2.5 years (see Sect. 2.2.2.3). Table 8 also presents the total hours per effective life per mode, based on percentage in office and home environments. These values are in bold in Table 8 (4,586 and 8,961 hrs per effective life) and will be used with the energy use rates per mode (presented in Sect. 2.1, Table 1), to calculate the total energy consumption per effective life for each monitor type.

Table 8. Effective Life Values

User Environment	Power Mode	First Life (4 years)		Remaining Lives (2.5 years)		Model Totals[b] (hr/effective life)
		Operating Pattern (hr/yr)	Total (hr/4 yrs)	Operating Pattern (hr/yr)[a]	Total (hrs/2.5 yrs)	
OFFICE (65%)	Full-on	1,095	4,380	493	1,233	5,613
	Low	2,263	9,052	1,018	2,545	11,597
HOME (35%)	Full-on	522	2,088	235	588	2,676
	Low	793	3,172	357	893	4,065
WEIGHTED AVERAGE[c]	Full-on	---	---	---	---	**4,585**
	Low	---	---	---	---	**8,961**

[a] The remaining lives operating pattern is 45% of first life operating pattern, based on 45% of monitors that are reused (Matthews et al. 1997).
[b] Modal totals calculated as [(Total for first 4 years) + (Total for remaining 2.5 years)].
[c] The weighted averages shown for full-on and low power modes are based on the assumption that 65% of users operate in an office environment and 35% operate in a home environment.

3. PRELIMINARY RESULTS

In order to calculate the total kWhs consumed per manufactured life and effective life, values from Sects. 2.1 and 2.2 were combined as shown in Tables 9A and 9B. First, the energy use rates (kW) were multiplied by the lifespans (hours per life) for each mode and each monitor type. They were then summed for the two power modes to obtain a total kWh/life for each monitor type. In an LCA, comparisons are made based on functional equivalency. Therefore, if one monitor will operate for a longer period of time than another, as in the manufactured life scenario, overall life-cycle impacts should be based on an equivalent use. Thus, because the manufactured life of an LCD is 3.6 times greater than a CRT (see Sect. 2.2.1), in the final analysis, the CRT manufacturing process inventories must be multiplied by 3.6 to retain a functionally equivalent basis for the CRT and LCD monitor comparison. Since the effective life calculation is not technology-dependent, both monitor types operate for the same number of hours in the effective life (see Table 8) and thus they are considered functionally equivalent and no modification to the overall life-cycle analysis is necessary.

Table 9A. Manufactured Life (ML) Electricity Consumption

Monitor Type	Power Mode	Energy Use Rate (kW)	ML Calculated Lifespan (hours/life)	ML Energy Consumption (kWh/life)
17" CRT	Full-on	0.113	6,250	706
	Low	0.013	6,250	81
	Total	----	12,500	787
15"LCD	Full-on	0.040	22,500	900
	Low	0.006	22,500	135
	Total	----	45,000	1,035

Table 9B. Effective Life (EL) Electricity Consumption

Monitor Type	Power Mode	Energy Use Rate (kW)	EL Calculated Lifespan (hours/life)	EL Energy Consumption (kWh/life)
17" CRT	Full-on	0.113	4,585	518
	Low	0.013	8,961	116
	Total	----	13,547	634
15"LCD	Full-on	0.040	4,585	183
	Low	0.006	8,961	54
	Total	----	13,547	237

3.1 Comparing Lifespans: Manufactured Life to Effective Life

Since the energy use rates are the same across both lifespan scenarios for CRTs and LCDs, we can compare the calculated lifespans of the manufactured and effective lives (hours per life). For the CRT monitor, the manufactured life total hours are 12,500 versus the effective life total of 13,547. While this does seem to suggest that a CRT can be used longer than is physically possible, what this brings out is the lower confidence we have in these numbers and some of their supporting values, with less confidence in the manufactured life data. Assumptions were required several times that could bias these numbers in either direction, however it is thought that most likely the manufactured life estimate is low based on the other estimates for the overall CRT monitor (see Attachment A, Table A2). However, there was no sound basis for assuming a lower value and thus the above hours per life values were used. It should also be stated that while these numbers are different, they are within an 8% error range of one another, and can be taken to be a near 1:1 ratio, indicating a similar potential lifespan.

For LCDs, the comparison across lifespan scenarios looks more like what one would expect, with the manufactured life value of 45,000 hours per life being much greater than the effective life value of 13,547 hours per life. The effective life value reflects the assumption that a user's use habits are not technology-dependent, and would seem to reveal that LCDs are not being used as long as they can physically be (less than a third as long).

The difference between the manufactured and effective lives are important when evaluating all the life-cycle stages for a particular monitor type. If the manufactured life is significantly greater than the effective life, the use stage will have greater impacts, as compared to other life-cycle stages. Therefore, it is important to focus on the lifetime scenario that is most realistic, while still recognizing the potential impacts from another feasible lifespan scenario.

In the final LCA for this project, we will use the effective life as the primary basis for the use stage inventory due to the fact that the effective life data are attempting to obtain a more realistic value for kWhs consumed per lifetime, and that we currently have greater confidence in those data versus the manufactured life data. The manufactured life data will be used to discuss potential differences in the use stage impacts based on this alternative lifetime scenario.

3.2 Sensitivity Analysis

Finally, in an effort to provide some sensitivity analysis to the final values, the assumption used in the effective life calculation that 10% of the computers manufactured in 1998 and currently in use are not able to take advantage of lower power-saving modes (a 90/10 split) was adjusted to three different splits, with all the other assumptions and calculations kept unchanged (50/50, 75/25 and 100/0, respectively in each case those that are able to go into power saving modes and those that are not). Table 10 presents the results of the sensitivity analysis for each of the four power-saving functionality scenarios.

Table 10. Sensitivity Analysis of Effective Life Results

Monitor Type	Power Mode		% that Can / % that Cannot Take Advantage of Power-Saving Features			
			50/50	75/25	**90/10**	100/0
17" CRT	Full-on	(kWh/life)	969	689	**518**	408
	Low		64	97	**116**	129
	Total		1,033	786	**634**	537
15" LCD	Full-on	(kWh/life)	343	244	**183**	145
	Low		30	45	**54**	60
	Total		373	289	**237**	205

The data in Table 10 reveal that the final electrical energy consumption values for the CRT would increase by 63% with a 50/50 split and decrease by 15% with a 100/0 split (from the 90/10 split assumption). Similarly for the LCD, the results would increase by 57% or decrease by 14%. Varying the use of power-saving features results in variations in the total amount of energy consumed for LCDs and CRTs, but does not vary the ratio of LCD to CRT energy use. Therefore, these variations will affect the magnitude of the use stage impacts for effective life scenarios when compared to other life-cycle stages, but will not affect the comparison of LCD to CRT. Additional sensitivity analyses are available in Socolof et al. (2000).

4. DATA SOURCES AND QUALITY

Source and quality information for the data utilized in this TM are detailed in Table 11. Four categories of data quality ratings were assigned: excellent, average, poor, and unknown. In general, data assigned higher quality ratings were directly measured and represent 1998 data. As data required more calculation or estimation, or were found from a previous year, the data quality rating was reduced.

In general, the overall level of data quality is between average and excellent. However, a distinct difference can be seen in the average data quality ratings given to manufactured life data (average) and the effective life data (excellent). This infers that greater confidence can be placed in the effective life data than in the manufactured life data. Additionally, the energy use rate data appears to be of average.

Table 11. Data Sources and Quality Information for the Use Life-Span Stage TM

Data	Data Source/References	Data Source Comments	Data Quality [a]	Data Quality Explanation
ENERGY USE RATE				
Various monitor manufacturer's energy use rate data	Web sites in most cases; E-mail from manufacturer in remaining cases.	It was assumed that the data provided by manufacturers on the Web sites were high-quality data in that the data should be measured and directly applicable to the equipment for which the information is provided. However, the search for information did not separate information obtained by performance level of the monitors.	Average	It was not possible to determine in what year each individual monitor was manufactured; however, it is assumed that each monitor is on the order of several months to 2 years old when promoted for sale. Thus it is estimated that the average date of the information obtained is probably relative to approximately 1997. Adding that the data was not sorted by performance level, this data was given a data quality rating of Average.
MANUFACTURED LIFE (Only those sources utilized to derive values are discussed here.)				
Discussion of CRT lifespan	McConnaughey 1999	Professional opinion provides good insights into potential ranges for certain components, however is still an opinion and not scientific data.	Average	As a computer manufacturing company employee, it is expected that they are a quality source of information on this topic; however, information is still an opinion and not scientific data, thus an Average data quality rating was assigned.
Discussion of CRT and LCD lifespans	Douglas 1999	See above comment.	Average	See above comment.
Discussion of LCD lifespan	Ritsko 1999	See above comment.	Average	See above comment.
Discussion of LCD lifespan	Tsuda 1999	See above comment.	Average	See above comment.
Discussion of CRT and LCD lifespans	Young 1999	See above comment.	Average	As the leader of a group that closely follows the trends in the LCD market and produces monthly reports on technology and market trends, it is expected that they are a quality source of information on this topic, however, information is still an opinion and not scientific data, thus an Average data quality rating was used.
17" CRT monitor specifications sheet	VP150 1998	As technical data on one specific CRT monitor the information is expected to be at least testing quality data or better.	Excellent	As direct manufacturer information applicable to 1998, this data is given an Excellent data quality rating.

Table 11. Data Sources and Quality Information for the Use Life-Span Stage TM

Data	Data Source/References	Data Source Comments	Data Quality [a]	Data Quality Explanation
EFFECTIVE LIFE				
Number of PCS in use in the U.S.	CIA 1997	Authors have much experience in obtaining and collecting computer statistics in U.S. and other countries; have been publishing this book since 1986.	Excellent	From review of the available information on the authors and data sources for the data that go into the Computer Industry Almanac, the data quality rating of Excellent is given. Even though data is from 1996, the authors used that data and recent trends information to predict 1997 values, and it is expected that the 1997 values are not significantly different than the 1998 values.
Percent of PCS in the home that are used in an office-like environment	RECS 1999	"The Residential Energy Consumption Survey provides national...information about U.S. households and their energy usage. The 1997 survey collected data from a statistically selected sample of 5,902 households that were interviewed in their homes."	Excellent	While these data are 1997 data, it is assumed that the energy usage patterns of home dwellers has not changed significantly between 1997 and 1998.
Number of PCs in use in the home	RECS 1999	See previous comment on RECS.	Excellent	See previous comment on RECS.
Office PC use pattern	Nordman 1996	Used multiple sources of previous data covering many samples of PCs, as well as their own research, to derive their equipment usage pattern.	Average	Their data was manipulated slightly to account for a greater number of affectors on typical usage patterns. By manipulating their data the data quality is slightly reduced, thus data quality rating of Average was assigned.
Home PC use pattern	RECS 1999	See previous comment on RECS.	Excellent	See previous comment on RECS.
Number of years PCS are used in 1st life and 2nd and subsequent lives	NSC 1999	"This study presents the results of the first large-scale survey (which covered the years 1997 and 1998) and analysis of end-of-life electronic product recycling and reuse in the U.S. Data were collected from 123 firms."	Excellent	Due to the applicable time frame and the body of companies who participated, these data were given data quality rating of Excellent.
Number of PCS that are used in their 2nd and subsequent lives	Matthews 1997	Performed a study in 1991, watched as the computer market changed over l6 years, then reviewed the original study finding the weak spots there. Reperformed study in 1997 making learned changes to the analysis format and using newer data (1997).	Average	While changes were made to the second study as weaker parts of previous study were uncovered, still extrapolated individual recycling firm data to obtain some base data for their estimates. While data is primarily relative to the 1997 time frame, which is very close to our year of interest of 1998, still chose data quality rating of Average due to amount of data manipulation that was required to obtain values.

[a] The data were assigned to one of the following four data quality categories: Excellent, Average, Poor, and Unknown.

5. LIMITATIONS & UNCERTAINTIES

This section is subdivided into three subsections, with each addressing the limitations and uncertainties of the energy use rate, manufactured life and effective life calculations.

5.1 Energy Use Rate

The energy use rates utilized in this TM were not from a systematic study of the energy use rates of all applicable monitors, only those for which information was located on the World Wide Web. Also, it was difficult to pinpoint the exact date from which much of the data came (see the data quality explanation of those data in Table 11). To successfully and effectively take advantage of the data on each of the three lower power modes, it would have been necessary to have hours per life data for each of the three power modes as well as for manufactured and effective lives. No sources of data, for either lifespan, separated hours per life estimates into three distinct low power modes. While this does induce error, it is expected that averaging those categories to estimate the total amount of time that a monitor spends in all the lower power modes would only have a minor effect on the final energy use rate values. The effect of averaging these categories probably overestimates the total amount of electrical energy that is consumed during lower-power mode use. This is so because those that are left on for significant periods of time (overnight, over a two-day weekend, or over an extended stay) most likely are reaching their lowest power mode within the first 1 - 2 hours and staying there for the duration of the away time.

When this information was obtained from the World Wide Web, the data were simply separated into one of the two large categories of 17" CRT and 15" LCD desktop monitors. Thus, since it is fairly common that one type of monitor manufacturer will make several different models with varying performance characteristics with one size range, a limitation of this data is that it is not sorted by performance characteristics. Additionally, the data obtained from these Web sites are most likely maximums, and were stated as such in several cases. However, if some manufacturers did not state that the reported values were maximums, then our averages are slightly high.

5.2 Manufactured Life

Only a very limited amount of information was obtained with which to make the assumptions made in this TM about manufactured life. The primary uncertainties relate not only to the assumption of the MTBF lifespan of the monitors, but also to the testing duty cycle which was completely estimated. With the lack of any high quality data, the confidence in the manufactured life calculations is low.

5.3 Effective Life

Several assumptions were made to calculate the effective life data set. They include the following:

- 90% of monitors are able to go into lower power consumption modes;
- Atypical workplace computers (e.g., those used in hospitals and schools) balance to fit the office-like use environment established in this TM;
- Atypical (average) office use environment week consists of 4 'weekdays,' 1 'absence day' and 2 'weekend days,' where the absence day accounts for holidays, sick days, work-related travel days, vacations and days of no use of the work computer;
- The percent of time a monitor spends in full-on versus lower power modes in a home environment is the same as in an office environment;
- Used the office environment split of the total on time that equipment spends in full-on versus a lower power mode for the home environment split of total on time;
- LCD desktop monitor lifetimes are more similar to desktop CRT monitors than notebook PC displays; and
- The same number of years of use per life exist for office and home environments.

While the above assumptions do introduce error, the magnitude of the error is unknown. Some assumptions may have a greater effect on the final values than others. For example, it may be concluded that the assumption that the average office PC system usage pattern is fairly accurate, while the assumption about atypical workplace computers could potentially contain significant error in either direction of the assumed value. Table 10 showed the effects on the results from varying the use of energy saving features. If several of these assumptions are biased in the same direction (either all underestimating or overestimating the results), then the effective life results have the potential to be significantly under or overestimated.

6. DISCUSSION AND CONCLUSIONS

The information presented in this TM are used to calculate the environmental burdens generated during the use life-cycle stage of the monitors. That information is then compared to those burdens that occur in the other four life-cycle stages of materials extraction, materials processing, manufacturing and end-of-life. To calculate the environmental burdens from the use life-cycle stage, the results of this TM -- the values for each monitor's electrical energy consumption over its lifetime in kWhs -- are multiplied by each of the inputs and outputs from the electricity generation process.

ACRONYMS & ABBREVIATIONS

CDP	Computer Display Project
CRT	Cathode ray tube
DfE	Design for the Environment
DOE	Department of Energy
DPMS	Display Power Management Signaling
EIA	Energy Information Administration
IC	Integrated circuit
kW	Kilowatt
kWh	Kilowatthour
LBNL	Lawrence Berkeley National Laboratory
LCA	Life-cycle assessment
LCD	Liquid crystal display
LCI	Life-cycle inventory
MTBF	Mean-time-before-failure
PC	Personal computer
RECS	Residential Energy Consumption Survey
TM	Technical memorandum
W	Watt

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Attachment A to Appendix H
Supporting Tables

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Table A-1. CRT & LCD Monitor Energy Consumption Values

CRTs	Company	Model	Size (inches)	VIS [a] (inches)	Energy Consumption (watts)								Comments/Assumptions
						Full-on		Standby [b]		Suspend		Act. Off	
	Apple	Color Sync	17.0	16.1	<	125	<	60			<	5	
		Multiple Scan 720	17.0	16.0	<	120					<	5	
	Compaq (& Digital)	V75	17.0	16.0	<	115							
		P75	17.0	16.0	<	115							
		71C	17.0	15.7	<	110	<	15	<	15	<	8	
		71P	17.0	16.0	<	120	<	15	<	15	<	8	
	EIZO	FlexScan TX-C7	17.0	15.8		140	<	12			<	5	
		FlexScan FX-C5	17.0	15.6		95	<	10			<	5	
	Hitachi	SuperScan Elite 641	17.0	15.9	<	135	<	15			<	8	
		SuperScan Pro 620	17.0	15.9	<	115	<	15			<	8	
	LG	Studioworks 74i	17.0	16.0		100		15				8	
		77M	17.0	15.9	<	130						5	
	MAG	XJ707	17.0		<	120	<	15	<	15	<	8	
		XJ717	17.0		<	120	<	10	<	10	<	5	
		XJ700T	17.0		<	120	<	15	<	15	<	5	
		DJ707 AV	17.0		<	120	<	15	<	15	<	8	
	Mitsubishi	Diamond 87TXM	17.0	16.0		120	<	100	<	15	<	8	Due to the significant difference in the Mitsubishi "Standby" power mode category values and those supplied by other manufacturers, these values were omitted from the average "Standby" power mode calculation.
		Diamond Pro 700	17.0	16.0		110	<	95	<	15			
		Diamond Plus 72	17.0	16.0		105	<	90	<	15			
		Diamond Plus 70	17.0	16.0		95	<	80	<	15			
	NEC	Multisyne A700	17.0	15.6		85					<	8	NEC representative contacted through support phone number stated that the energy saver mode power consumption is usually rated at 8 watts or less for all monitors. Due to range similarities, assumed that this rating falls into the 'Active Off' power mode consumption category.
		Multisync E700	17.0	15.6		95					<	8	
		Multisync M700	17.0	15.6		120					<	8	
		Multisync P750	17.0	15.6		125					<	8	
	Panasonic	PanaSync S17	17.0	16.0		110	<	15	<	15	<	8	The company Web site stated "typical" or "nominal" for the associated power consumption values.
		PanaMedia PM17	17.0	16.0		130	<	20	<	20	<	8	
	Philips	107S	17.0	15.9		80					<	5	
		107MB	17.0	15.9		85					<	5	
		107B	17.0	16.0		85					<	5	
	Sony	CPD-200ES	17.0	16.0	<	120	<	15			<	8	
		CPD-200GS	17.0	16.0	<	120	<	15			<	8	
	Toshiba	TekBright 700P	17.0	15.8		100							Web site indicated 110 watts maximum, 100 watts nominal.
	Viewsonic	PT775	17.0	16.0		130							The company Web site stated "typical" or "nominal" for the associated power consumption values.
		EA771B	17.0	16.0		130							
		G773	17.0	16.0	<	110							
CRT Averages:						113.00		17.31		15.00		6.85	
Standard deviations:						15.35		11.61		2.13		1.49	
CRT Standby, Suspend and Active Off average:								13.05					
Standard deviation:								5.08					

Table A1. CRT & LCD Monitor Energy Consumption Values (continued)

LCDs	Company	Model	Size/VIS [a] (inches)		Energy Consumption (watts) Full-on		Standby [b]		Suspend		Act. Off	Comments/Assumptions
	Apple	Studio Display	15.1	<	35		10				8	
	Batron	FM-17TX11	15.0		35							
	Compaq	TFT500	15.0	<	50							
	Digital	51P	15.0		40		8				8	Received data through phone support (800.354.9000).
	EIZO	FlexScan L34	15.0		30	<	15			<	5	
	LG	500LC	15.1		40		5				5	
	Mitsubishi	LCD50	15.0		45		8				8	
	NEC	LCD1510	15.0		50		8					
	Samsung	500TFT	15.0	<	45					<	5	Received data via E-mail. The Samsung E-mail received stated that in full power on mode, the power consumption was a maximum of 45 watts and a nominal of 36 watts.
	Sharp	Super-V	15.0		36						2	
	Sony	CDP-L150	15.0	<	35	<	4			<	4	
	Viewsonic	VP150	15.0		35		2.6				2.6	Received data via E-mail. Full-on category value noted as "typical."
LCD Averages:					39.67		7.58				5.29	
Standard deviations:					6.50		3.89				2.29	
LCD Standby, Suspend and Active Off average:									6.44			
Standard deviation:									3.09			

[a] VIS = Viewable Image Size.
[b] The 'Standby' energy consumption category includes listings noted as "Power Save Mode 1."

Notes: The energy consumption data shown in this table were taken from the Web sites of the retailers during 1998 unless otherwise noted. The energy consumption ratings for these monitors showed various information. Sometimes the less than (<) symbol preceeded some or all values, sometimes the addendum note 'maximum' was included and sometimes only the values themselves were reported.

Table A2. CRT and LCD Monitor MTBF Values & Manufactured Life Comments

MTBF Values for the:			Source	Comments from Sources
CRT Monitor	CRT Only	LCD Monitor		
(thousand hours)				
30-60	10-15		Goldwasser 1999	- "Most manufacturers will quote an MTBF of somewhere in the 30,000 to 60,000 hour range, EXCLUSIVE of the CRT. The typical CRT, without an extended-life cathode, is usually good for 10,000 to 15,000 hours before it reaches half its initial brightness." - "CRT Life: The life of a monitor is determined by the life of the CRT. The CRT is by far the most expensive single part and it is usually not worth repairing a monitor in which the CRT requires replacement. The brightness half-life of a CRT is usually about 10-15k hours of on time independent of what is being displayed on the screen." - "In a CRT monitor, the shortest-lived component BY FAR is the CRT itself, and it ages (more properly, the cathode is aging) as long as the heater is on and the tube is under bias (i.e., receiving voltage). Most monitors don't get around to turning the heater down or off until they enter the Display Power Management Signaling (DPMS) "suspend" or "off" modes. (And no, screen-savers do NOT help here - the tube is still on and the cathode is aging.) - "In a CRT display, the CRT itself is usually the limiting factor in this (life), and in THAT specific case we usually speak of "mean time to half-bright" instead, since it's rare for a CRT to simply die once it's past its early operating life. Mean-time-to-half-bright is just what it says: how long, on average, can you operate the tube before the brightness drops to half its initial level for a given set of operating conditions. (Brightness is ALWAYS slow(ly) decreasing throughout the tube's life, due to the aging of the cathode and the phosphor.) For most tubes with standard cathodes, this will be in the neighborhood of 10,000-15,000 hours."
50-100			McConnaughey 1999	Mr. McConnaughey stated that each of the subsystems of a monitor has different components that must meet different MTBF (Mean Time Before Failure) testing. Before testing, manufacturers typically calculate what the expected MTBF should be, and then test it to obtain the demonstrated MTBF. A rule of thumb is 50,000 hours calculated and over 100,000 hours demonstrated.
75			Philips 1998	"MTBF: >75,000 h (according to MIL-HDBK 217E) at 25 degrees Celsius (excl. CRT)"
50			Maginnovision 1998	"The average MTBF (Mean Time Before Failure) for MAG InnoVision monitors is 50,000 hours, excluding the CRT."
86			PlanetMac 1999	Mean Time Before Failure = 86,000 hours.
80	10-15	(50-backlights)	Douglas 1999	Phone conversation with David Douglas at Dell in Texas. David took plenty of time to discuss MTBF, and relayed that while Dell requires suppliers of CRT components (EXCLUDING THE CRT) to meet a MTBF specification of 80,000 hours, Dell performs testing (a type of 'demonstrated' MTBF - is a torture test) that typically yields at least twice the specification value in total time the equipment can operate. With that said, David then agreed that the CRT is the component that determines a CRT-based monitor's lifetime and that it is rare that a CRT lasts anywhere near that long, with most failing in the 10,000-15,000 hours/life range. David noted that CRT semiconductors are the next component that can fail. In LCDs, components containing silicon are most likely to fail first, with most manufacturers quoting backlights that will last 50,000 hours.
			Koch 1996	Didn't supply any other data other than that they assumed 10,000 hours as the lifespan of the LCD monitor.

APPENDIX H

Table A2. CRT and LCD Monitor MTBF Values & Manufactured Life Comments

MTBF Values for the:			Source	Comments from Sources
CRT Monitor	CRT Only	LCD Monitor		
(thousand hours)				
		50: 15 for backlights	Tsuda 1999	Mr. Tsuda (Apple Computers) stated that the specs don't typically change for different size LCD monitors for specific components. MTBFs for flat panel displays are about 50,000 hours, except for the backlights which have MTBFs of about 15,000 hours. Most components can be fixed or replaced easily by trained technicians. Testing they perform is with maximum brightness, full white pattern; worst pattern for LCD is 1 pixel On/1 pixel Off.
		40	Young 1999	Through a conversation with Ross Young, Ross spoke of a note a gentlemen had sent him wherein they assumed a useful life for an LCD of 84 months and a CRT of 36 months. Additionally, it was noted that an LCD panel was assumed to have a life of around 40,000 hours, and this could increase if DPMS screen savers were implemented.
		(50- backlights)	VP150 1998	Light Source: long life, 50,000 hrs. (typ)
		(10-40 - silicon driver chips)	Ritsko 1999	Liquid crystals and thin-film transistors (TFTs) don't typically wear out, yet the amorphous silicon transistors are less reliable than the single transistors. Also, the driver (silicon) chips could be an item that might show wear, however, the chips that go in FPDs are fairly typical, use low voltages and should run between 10,000 and 40,000 hours.

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Table A3. Use Stage Data Information, Estimates and Assumptions from Reviewed Sources

Author	Operating Circumstances/Lifetime Data			Power Consumption rate/Power Management
Jung 1999	"The estimated useful life for a PC in a business environment is only two to three years, while home computers users typically use their equipment for three to five years."			
Matthews 1997	First research group to attempt to model the time effort factor of storage of computer equipment during the Use life-cycle stage. In doing so, came up with a breakdown of options (shown below). Additionally, after calculating the destinations and percent averages from their numbers, 26% of end-of-life equipment is landfilled after 8.06 years in use and storage (and possible reuse), and 74% is recycled after 8.49 years in use, storage and possible reuse.			
	Initial lifetime of PCs: 5 years	% at end of 1st life reused:	45%	
		% at end of 1st life recycled:	5%	
		% at end of 1st life stockpiled:	45%	
		% at end of 1st life landfilled:	5%	
	Lifetime of reused PC: 3 years	% reused recycled:	40%	
		% reused stockpiled:	50%	
		% reused landfilled:	10%	
	Lifetime of stockpiled PC: 3 years	% stored recycled:	75%	
		% stored landfilled:	25%	
	Calculating through the above numbers for 100 computers reveals the following breakdown:	(# out of 100)	(time)	
	Landfilled after 5 years	5	25	
	Landfilled after 8 years	15.5	124	
	Landfilled after 11 years	5.5	60.5	
	Landfilled totals	26	209.5	
	Average numbers of years to landfilling of PC:		8.06	
	Recycled after 5 years	5	25	
	Recycled after 8 years	52	416	
	Recycled after 11 years	17	187	
	Recycled totals	74	628	
	Average number of years to recycling of PC:		8.49	
NSC 1999	"The lifespan estimates used in this study were developed through interviews with more than 30 major manufacturers and resellers. Major computer manufacturers were consulted to determine the lifespan of electronic equipment. Because manufacturers know when their products were fabricated and many also have recycling facilities, these firms are qualified to make an educated lifespan estimate. Resellers and nonprofit organizations were asked to estimate the reusable life or 'second life' by product and processor type. These inputs were used to develop estimates of the first life (the amount of time a product is useful to its original owner) and the total lifespan (period from manufacturers to disposal) for each electronic product."			
		First life	Total life	
	CRT computer	4	6-7	
	Notebook PC	2-3	4	

Table A3. Use Stage Data Information, Estimates and Assumptions from Reviewed Sources

Author	Operating Circumstances/Lifetime Data			Power Consumption rate/Power Management
Chan 1997	This class report from a University of Toronto group of 4 people contains several worthwhile pieces of information. The data presented comprise responses from 180 people (130 administrative, teaching and research staff and 50 residents). Class covered 1996/1997; data were gathered during the class.			
	Hours of computer use by staff	< 4 hrs/dy	7%	
		5-8 hrs/dy	52%	
		9 or > hrs/dy	41%	
	Percentage of computers with energy-saving features installed or activated	have features	52%	
		no knowledge of features	35%	
		don't have features installed or	13%	
	Respondents who update their knowledge of computer energy-saving features	do not	75%	
		do	19%	
		no response	6%	
	Idling time of office and residential computers that are turned on	less than 2 hrs	66%	
		3-5 hrs.	22%	
		6 hrs or more	12%	
	Respondents who turn off their computer when they are away for a period (period is 45 min. or longer)	never do	70%	
		sometimes do	21%	
		always do	7%	
		no control	25%	
	Staff who shut down their computers at the end of the day	always	70%	
		sometimes	9%	
		never	19%	
		no control	2%	
	Percent of office computers left on during weekends	always	22%	
		sometimes	8%	
		never	67%	
		no control/no response	3%	
EIA 1997	The EIA's results from the Residential Energy Consumption Survey (RECS) provides some good data on			
	Hours PC turned on each week	less than 2 hrs	8.2	
		2 to 15 hrs	17.4	
		16 to 40 hrs	6.7	
		On all the time	3.3	
	How PC is used	15 hrs a week or less	26.5	
		16 hrs a week or more	10.0	
		Personal use only	4.8	

Table A3. Use Stage Data Information, Estimates and Assumptions from Reviewed Sources

Author	Operating Circumstances/Lifetime Data			Power Consumption rate/Power Management
		Business use only	2.1	
		Used for both	3.1	
	Additionally, RECS calculated that lion computers were in use in U.S. households in 1997. Other data from the RECS included "6% of the households that used PCs used that computer to tele-commute."			
CIA 1998	Estimate that 117 million computers were in use in the U.S. in 1997.			
EPA 1999	Have the EnergyStar compliance monitor specifications.			
		First low-power mode	Second	
	Low-power state:	< = 15 watts	< =8W	
	Default times:	15-30 minutes	< 70 min.	
Koch 1997	Assumed 10,000 hours/lifetime for the LCDs in the study.			
Goldberg 1998	Article reported that Walt Rosenberg, Compaq's director of environmental affairs, stated that today's machines have a useful life of two-to-three years.			
Miseli 1999	Did not separate office from home user. Assumed units operate 50% of the time (annually) around the clock. Stated that "True life of a CRT or LCD is defined for the case when it runs continually at full intensity," adding that true life for CRT is about 1.25 years and for LCD is about 2.9 years. Doubled each of those true life values for his calculations.			Assumed 90W for a CRT and 30W for an LCD.
Tekawa 1997	Assumed personal users time frame of 2 hr/dy, 365 dy/yr for 5 years, and office users time frame of 8 hr/dy, 247 dy/yr for 7 years. Assumed a ratio of personal to office user of 4.6.			Don't state the actual numbers they used, but do say they took the mean of the minimum and maximum power consumption ratings.
Atlantic 1998	They estimated that a PC's lifetime is 3 years. Then they stated that they were modeling only the first lifetime of a PC; they acknowledged other lifetimes but decided not to attempt to model them. They also estimated that the PC is turned on 8 hrs per day, 230 days per yr, altogether running for 5,520 hrs during its lifetime.			They assumed that the monitor consumes power at a rate of 100W, and that the "base case PC has no energy savings facilities."
Philips 1998	MTBF of 75,000 hrs for a 19" C1995 Typhoon high resolution CRT monitor excluding the CRT.			Power consumption: 120W typ. (140 W max)
Nordman 1996	In this document, Lawrence Berkley National Laboratory (LBNL) details results from several audits they performed determining the state of power consumption and power management in certain computers and monitors			The LBNL document provided results from a audit of 70 monitors and their setup and use of energy saving power modes. Their primary conclusions were that only approximately one-third of all monitors were "accomplishing power management." The following is a breakdown of some of what they found:
	Standard % of time in each mode by day type, by operating pattern	Full-on	Low	- 34 apparently meet Energy Star requirements
	Workday	17%	35%	- 30 were 'universal,' (able to initiate power mgmt two ways)
	Weekend day	0%	20%	- 30 were left on at time of audit (12 in suspend mode)
	Absence day	0%	20%	
	Weekdays average	13%	45%	
	All days average	10%	35%	
				This document also contained data on the actual power consumed by 3-17" monitors over a 4-6 week period, broken down by power consumption mode, and the results are shown below:
				Monitor #1: Full-on = 91 watts; Low = 7 watts
				Monitor #2: Full-on = 84 watts; Low = 3 watts
				Monitor #3: Full-on= 85 watts; Low = 4 watts

Table A3. Use Stage Data Information, Estimates and Assumptions from Reviewed Sources

Author	Operating Circumstances/Lifetime Data	Power Consumption rate/Power Management		
CCPCT 1998		The University of Tennessee CCPCT reviewed the available CRT and LCD energy consumption information (mostly via the WWW) and produced the energy consumption breakdown shown at left by energy consuming state. The units are all watts.		
		CRT	Full-on:	113.29
			Standby:	17.18
			Active off:	6.85
		LCD	Full-on:	40.00
			Standby:	7.58
			Active-off:	5.70

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